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Effects of ultrasound treatment on the appearance characteristics of apple slices during osmotic dehydration

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ABSTRACT

Osmotic dehydration (OD) is an easy method for removing water from fruit and vegetable particles. In this study, apple slices were osmotically dehydrated in different hypertonic sucrose solutions and assisted with or without ultrasound. Sucrose concentrations, sonication power, and treatment time were the factors investigated concerning color parameters and surface area changes of the apple slices during OD. As the sonication power increased from 0W to 150W, the lightness (*L**) index values of apple slices reduced from 80.01 to 74.33. Also, with increasing sucrose solution concentration from 30°Brix to 50°Brix the lightness index values of apple slices decreased from 79.23 to 75.65. The results showed that the mean of *a** and *b** indexes values of dehydrated apple slices increased during the OD period. The highest total color difference (ΔE) index (23.4) and lowest surface area (7.98 cm^2) values were for the apple slices treated by the highest ultrasound power (150W, 40 kHz) and the highest sucrose solution concentration (50°Brix). The average surface area of fresh apple slices, dehydrated samples, hot-air drying samples, and rehydrated samples was 10.00 cm^2, 8.62 cm^2, 5.61 cm^2, and 6.99 cm^2, respectively. The results illustrated that the logistic equation was the best equation to explain the Δ*E* index changes of untreated and treated apple slices during OD.

1- Introduction

In ultrasound-assisted OD, ultrasonic waves could cause "sponge effect" and "cavitation effect," which is considered to be responsible for the creation of microscopic channels in the fruit and vegetable particles, facilitating the removal of water [1, 2]. The use of continuous high-frequency sonication improves the water transport rate during osmo-concentration. Also, the reduction of dehydration time and, as a result, processing costs have lately been reported at the laboratory scale after research conducted on some fruit and vegetable particles [3-5]. The various ultrasound-assisted OD conducted in multiple fruit and vegetable particles such as apple [6, 7], chinese ginger [1], cranberry [8], garlic [9], kiwifruit [10-12], papayas [13], persimmon [14], plum [15], pumpkin [16], quince [17], strawberry [5], and tomato [18] were increased the water loss rates and reduced the dehydration time. Nowacka, *et al.* [4] examined the use of sonication as a mass transport improving technique before the dehydration of apple slices. The application of ultrasound caused a decrease in the drying time of about 31% - 40% compared to untreated samples. The impact of ultrasound application on the water state in kiwifruit slices during OD was investigated by Nowacka, *et al.* [10]. The results confirmed that ultrasound application performed for more than 10 min has a positive impact on the mass exchange caused by OD. In another study, the impact of sonication (35 kHz for 10, 20, and 30 min) and OD treatment (30°C and 45°Brix) on convective drying and quality characteristics of persimmon fruit was studied by Bozkir, *et al.* [14]. This procedure increased water reduction and soluble solids gain of persimmon samples. Fijalkowska, *et al.* [7] studied the influence of sonication pretreatment (21 and 35 kHz for 30 min) on drying kinetics and physicochemical characteristic of dried apple pieces. They reported that the ultrasound pretreatments declined the drying duration of apple slices by 13–17% in comparison with the untreated slices. Ultrasound-assisted is considered a novel method that can be used to intensify slow processes [19]. The purpose of this study was to examine the influence of the use of ultrasound during OD in sucrose solution on the color parameters (L^*, a^*, b^*, and ΔE) and the surface area changes of apple slices. In addition, the ΔE index changes of apple slices during OD were modeled.

2. Materials and Methods

2.1. Samples preparation

The fresh (matured) apples (*Golden delicious*) were harvested in a patch located in Maragheh, East Azerbaijan Province, Iran in January 2022. The fresh apples were washed to remove the filth from them. They were then sliced into a uniform dimension (5 mm thickness) using a sharp knife and a cylindrical shape mold cut. The average initial moisture content (MC, 85.7% wet basis) of the fresh apple was determined by the AOAC method.

2.2. Osmosonication

The osmosonication (OS) was performed using ultrasonic equipment (vCLEAN1-L6, Backer, Iran). The apple slices were immersed in the ultrasonic bath containing 30%, 40%, and 50% (w/w) sucrose solutions which were sonicated at the frequency of 40 kHz, powers (0, 75, and 150 W), time intervals (10, 20, 30, 40, 50, and 60 min), and temperature (50°C). At the end of the pretreatment process, the osmosonicated apple slices were taken from the solution and cleaned with tissue paper. This method was replicated three times. The percentage of sucrose concentrations, ultrasound powers, temperature, and pretreatment times used were determined by preliminary experiments. The control sample was the untreated apple slices (0 W). After each treatment, the osmotic dehydrated apple slices were placed in a forced circulation air drying oven (105°C, Shimaz, Iran), until reaching a constant weight. Rehydration trials were performed carried out at 50°C for 20 min [20].

2.3. Surface color and area

The color analysis of untreated (control) and treated dehydrated apple samples was assessed from all the various treatment conditions using A scanner (HP Scanjet-300) and image analysis software (Image J, V.1.42e, USA), which gave $L^*a^*b^*$ and ΔE values. L^* value represents lightness, a^* value represents redness, b^* value represents yellowness, and ΔE value represents total color difference. Before the color assessment, a calibration plate was used to standardize the instrument (colorimeter) [21]. Also, the surface area of the apple slice during OD was calculated using the threshold color plugin in the image analysis software (Image J, V.1.42e, USA).

2.4. Kinetic modeling

The ΔE index changes during the OD procedure were modeled using the power equation, quadratic equation, and sigmoidal equations (Gompertz, Logistic, Richards, Morgan-Mercer-Flodin (MMF), and Weibull) [22, 23]. The coefficients of these equations were estimated using Matlab software (version R2012a). The square of the correlation between the response data and the expected response data (R-square or R^2), the sum of squares due to error (SSE), and the root mean squared error (RMSE) were the three criteria used to evaluate the experimental data adjustment. When the highest R^2 value is combined with the lowest SSE and RMSE values, a satisfactory fit between the actual data and the correlations is established.

2.5. Statistical analysis

The experimental data obtained were presented as the means of three determination values and standard deviation. The data were analyzed by one-way analysis of variance, Duncan test for comparison of the means was assessed at $p<0.05$ using SAS version 9.1 (SAS Institute Inc., USA).

3. Results and Discussion

3.1. Color indexes of apple slices

Deformation of porous solid materials caused by ultrasonic waves reduces the diffusion boundary layer and increases the convective mass transfer in the fruit slices [1]. The relation of OD is mainly related to enhancing some appearance, color, physicochemical, nutritional, functional, and sensorial characteristics of the dehydrated product [6, 7]. Figure 1 shows the impacts of sonication treatment (150W and 30°Brix) on the color and surface area of apple slices after OD, hot-air drying, and rehydration process. Figure 2 shows variations of the lightness parameter of apple slices during OD. As seen from this figure, sonication power and sucrose solution concentration play an essential role in the lightness index changes. *L** index values of untreated and treated apple slices with ultrasound decreased during OD, however, the rate of the lightness index changes was higher for the treated samples with ultrasound. As the sonication power (40 kHz) increased from 0W to 150W, the lightness index values of apple slices reduced from 80.01 to 74.33 ($p<0.05$). Also, with increasing sucrose solution concentration from 30°Brix to 50°Brix the lightness index values of apple slices decreased from 79.23 to 75.65 ($p<0.05$).

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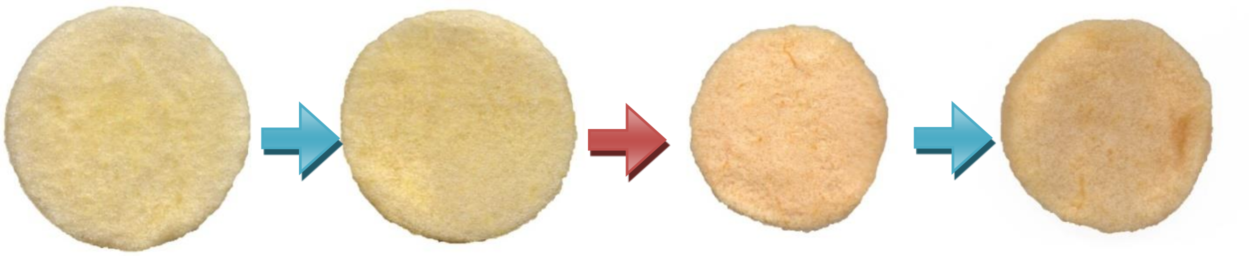
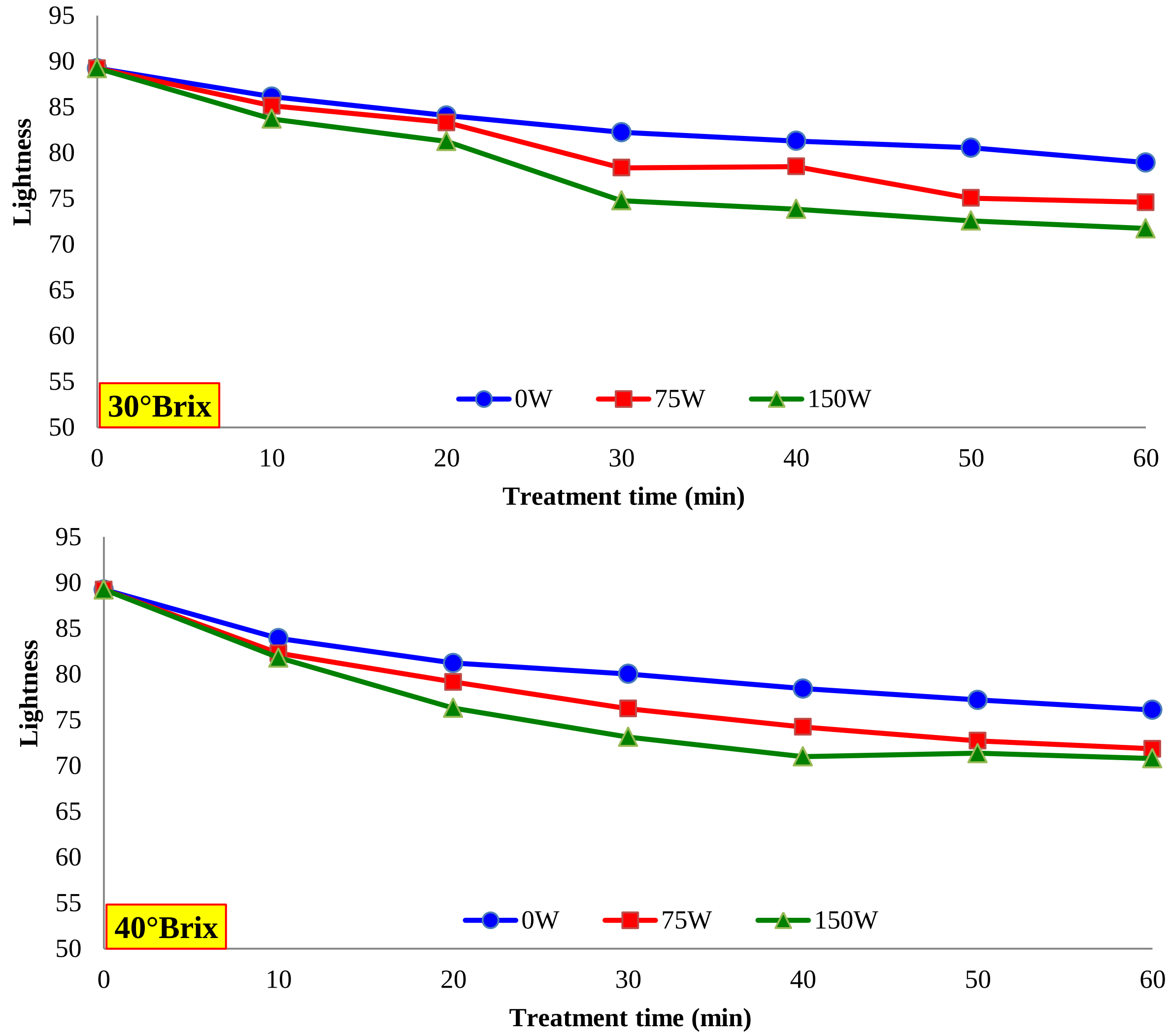


Figure 1. Impacts of sonication treatment (150W and 30°Brix) on the color and surface area (shrinkage) of apple slices during the osmotic dehydration process.



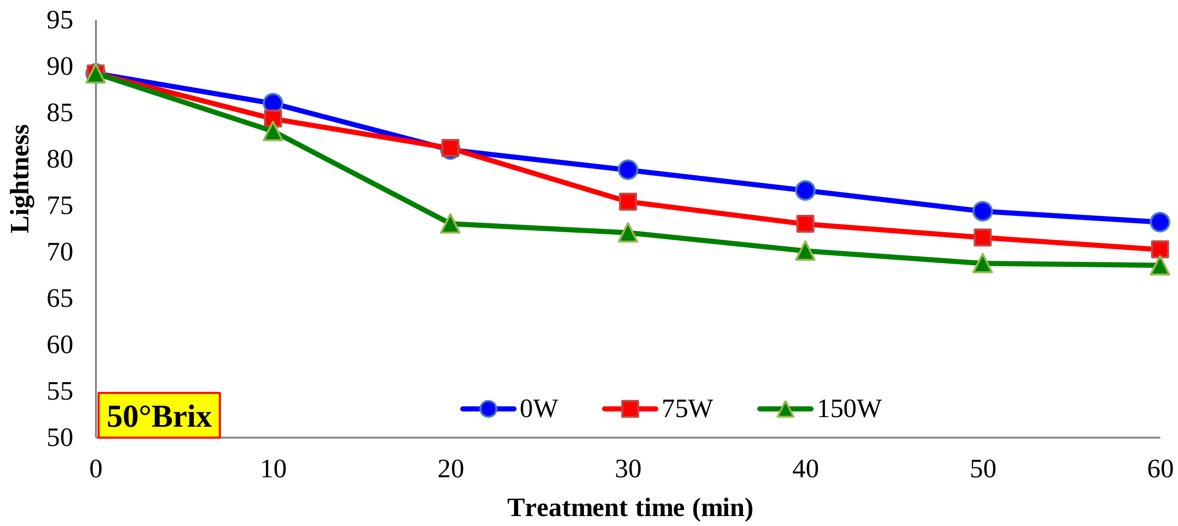


Figure 2. Impacts of sonication power, sucrose solution concentration, and treatment time on the lightness index (L^*) of apple slices during osmotic dehydration.

In Table 1 the mean color indexes of untreated and treated apple slices by ultrasound after OD were reported. It was considered that the lightness index decreased with increasing in the sonication power and sucrose concentration. The fresh apple slices exhibited a light color, with L^*, a^*, and b^* equal to 89.24, -0.33, and 23.06, respectively. After the dehydration process apple slices, we measured the surface color of samples and the average of L^*, a^*, and b^* indexes values for dehydrated apple slices were 77.14, 0.01, and 30.38, respectively. These data indicated that the lightness of dehydrated apple slices was decreased after OD process, but, the redness and yellowness indexes of samples were increased. Similar findings were reported by Rahaman, *et al.* [15], where the authors reported that color of ultrasound-assisted osmotic dehydrated plum was influenced by sonication time (30 and 60 minutes) and the type of osmotic solution (50% glucose and sucrose).

Table 1. Mean of color indexes of untreated and treated apple slices by ultrasound after osmotic dehydration.

Sucrose solution concentration	Ultrasound treatment	Yellowness (b^*)	Redness (a^*)	Lightness (L^*)
	Untreated (0W)	28.3 ± 1.6	-1.1 ± 0.4	82.2 ± 2.3
30°Brix	**Treated (75W)**	31.2 ± 2.1	-1.4 ± 0.3	79.2 ± 3.9
	Treated (150W)	33.2 ± 1.4	1.6 ± 2.1	76.3 ± 4.5
	Untreated (0W)	27.7 ± 1.3	-1.1 ± 0.5	79.5 ± 2.6
40°Brix	**Treated (75W)**	29.3 ± 3.1	-0.9 ± 1.0	76.1 ± 3.7
	Treated (150W)	34.1 ± 1.5	2.1 ± 1.7	74.1 ± 3.9
	Untreated (0W)	27.9 ± 1.6	-0.9 ± 1.3	78.4 ± 4.3
50°Brix	**Treated (75W)**	31.3 ± 1.7	-1.5 ± 1.1	76.0 ± 5.1
	Treated (150W)	30.2 ± 2.4	3.3 ± 2.1	72.6 ± 4.9

In addition, in Table 2 the mean of color parameters and surface area of dehydrated apple slices after drying by hot-air were reported. Our results showed that the average L^*, a^*, and b^* indexes values for dried apple slices were 73.50, 11.83, and 36.55, respectively. These data indicated that the lightness of dried apple slices decreased after the drying process, but, the redness and yellowness indexes of dried samples increased. It was considered that the lightness index of dried apple slices decreased with increasing in the sonication power and sucrose concentration. As the sonication power (40 kHz) increased from 0W to 150W, the lightness index values of dried apple slices reduced from 75.42 to 71.45 ($p<0.05$). Also, with increasing sucrose solution concentration from 30°Brix to 50°Brix the lightness index values of dried apple slices decreased from 75.22 to 72.24 ($p<0.05$). Also, in this table, the average surface area of dried apple slices after different pretreatment was reported. In summary, during the hot-air drying process, the surface area of dried apple slices decreased from 8.62 cm^2 to 5.61 cm^2. The results showed that with increasing sucrose solution concentration from 30°Brix to 50°Brix the surface area of dried apple slices increased from 5.42 cm^2 to 5.82 cm^2 ($p>0.05$).

Table 2. Mean of color indexes and surface area of dehydrated apple slices after drying by hot-air.

Sucrose solution concentration	**Ultrasound treatment**	**Yellowness (b^*)**	**Redness (a^*)**	**Lightness (L^*)**	**Surface area (cm^2)**
	Untreated (0W)	34.4 ± 1.5	9.5 ± 1.6	78.1 ± 2.2	5.21 ± 0.28
30°Brix	**Treated (75W)**	37.1 ± 1.3	13.9 ± 1.2	74.2 ± 2.1	5.10 ± 0.33
	Treated (150W)	34.9 ± 2.5	11.0 ± 2.4	73.9 ± 3.5	5.94 ± 0.38
	Untreated (0W)	37.2 ± 0.8	9.0 ± 1.8	75.5 ± 4.5	5.88 ± 0.42
40°Brix	**Treated (75W)**	38.2 ± 3.1	12.3 ± 2.6	73.7 ± 3.8	5.46 ± 0.24
	Treated (150W)	36.2 ± 2.2	11.7 ± 1.4	71.7 ± 3.5	5.49 ± 0.21
	Untreated (0W)	36.3 ± 2.0	13.3 ± 2.2	72.0 ± 3.6	5.51 ± 0.28
50°Brix	**Treated (75W)**	37.4 ± 1.4	15.0 ± 2.9	71.3 ± 3.0	5.94 ± 0.23
	Treated (150W)	37.2 ± 1.7	11.0 ± 1.4	71.1 ±1.8	6.00 ± 0.27

After the rehydration process of dried apple slices, we measured the surface color of samples and the average of L*, a*, and b* indexes values for rehydrated apple slices were 69.59, 10.08, and 35.27, respectively. These data indicated that the lightness, redness, and yellowness indexes of rehydrated apple slices were decreased after the rehydration process.

The use of sonication treatment during the OD is cause changes in color indexes. Also, the water loss and soluble solids gain and treatment time during the OD procedure assisted by ultrasonic also influence the surface color of fruit or vegetable particles [15, 18]. Figure 3 demonstrates the impacts of sonication power, osmotic solution concentration (°Brix), and treatment time on the ΔE index of apple slices during OD. It was observed that the ΔE index increased from 10.76 to 18.26 with the increase in sonication power from 0 to 150 W, and increased from 13.05 to 15.57 with the increasing in osmotic solution concentration from 30°Brix to 50°Brix ($p>0.05$). As well, with increasing treatments time, the total color difference index of dehydrated apple slices increased. Feng, *et al.* [9] results confirmed that the ΔE index of garlic slices dehydrated with vacuum pre-treatment coupled to ultrasound-assisted OD were higher than other OD techniques (including commonly OD, vacuum pre-treatment OD and multi-frequency mode ultrasound-assisted OD) in the first 30 min period of the treatment procedure. The higher water loss was the main important feature of this condition that might be the main reason for the color changes of samples.

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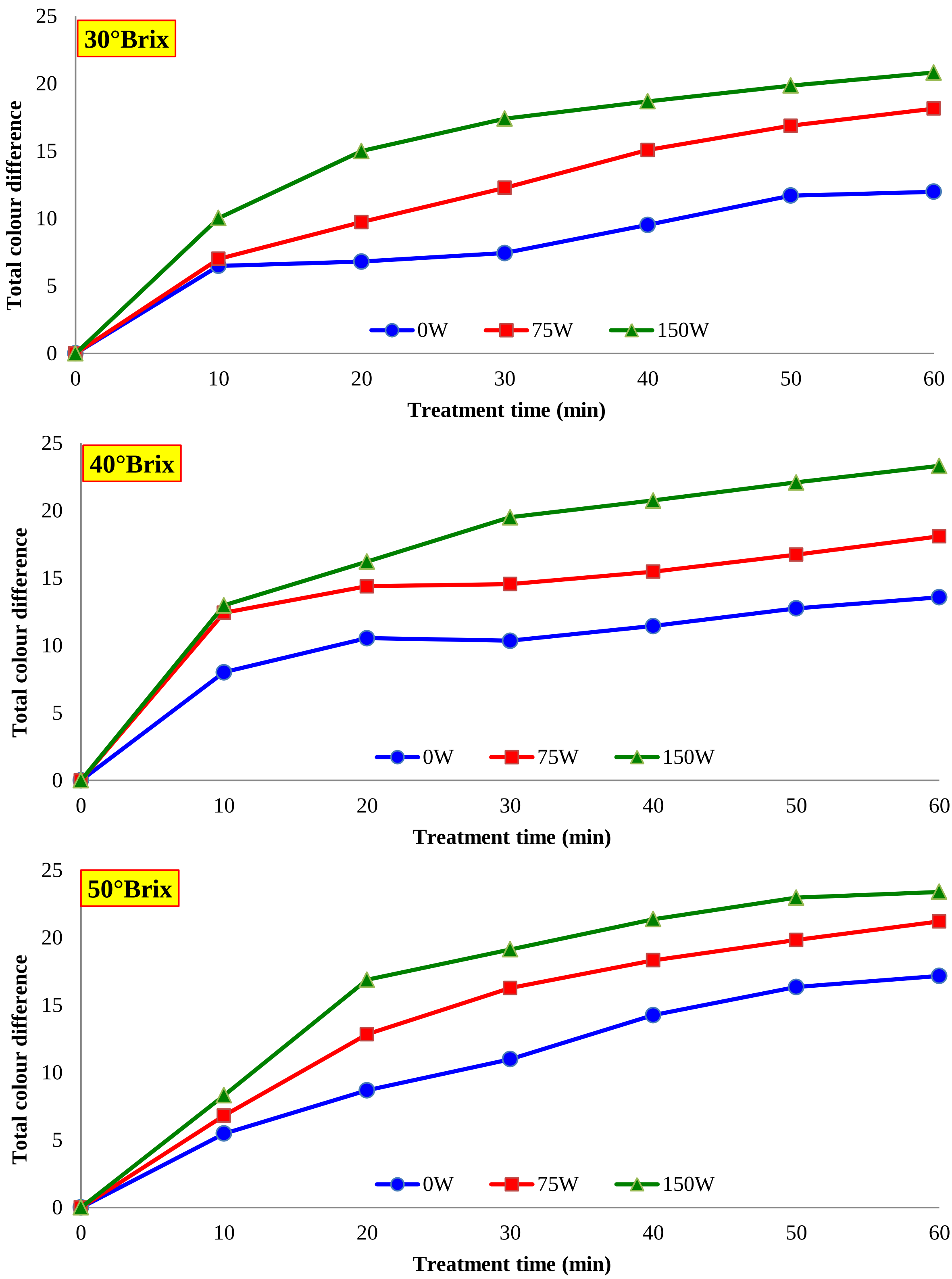
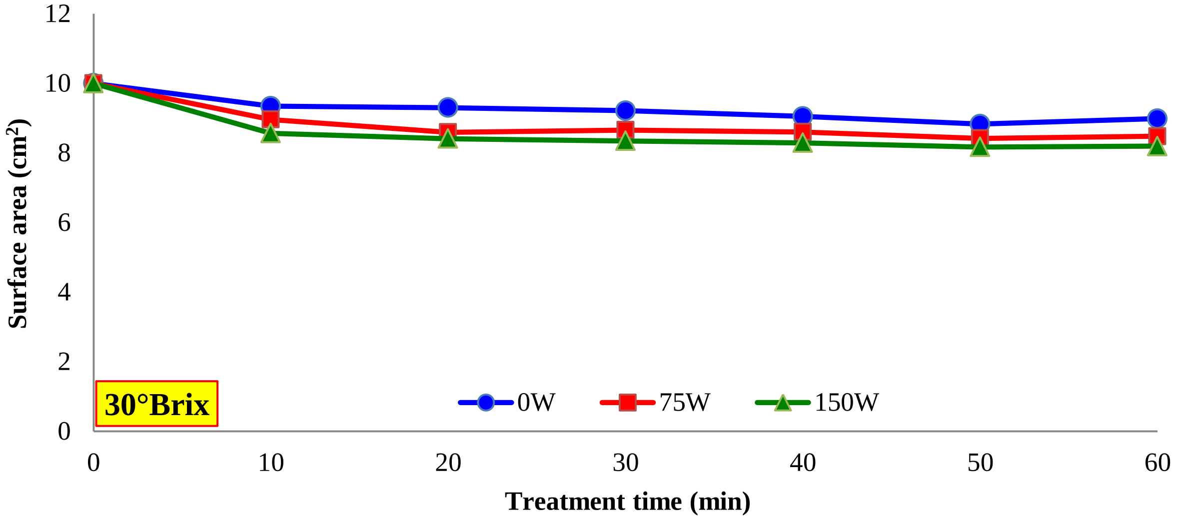
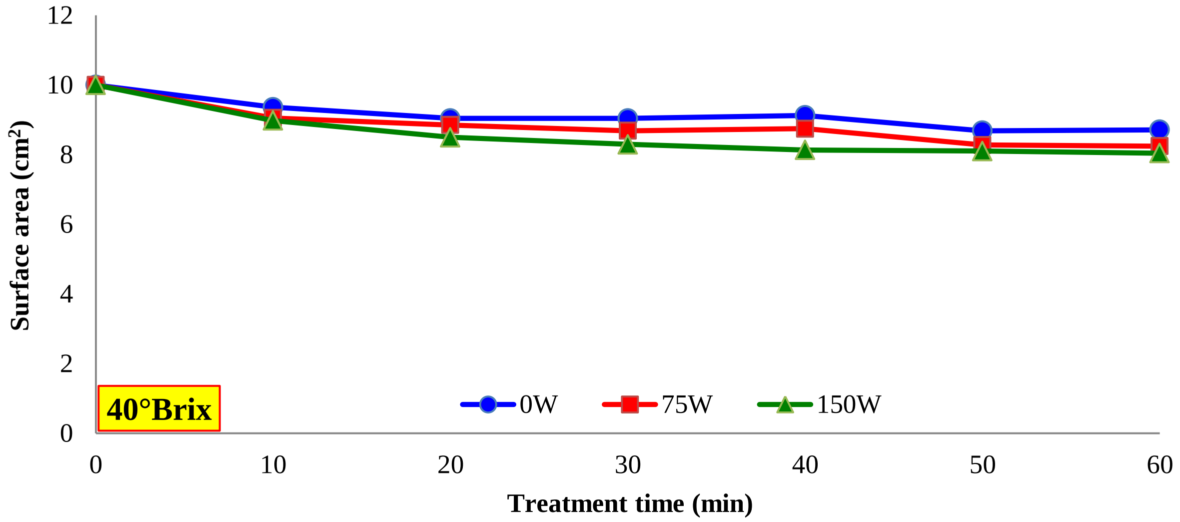


Figure 3. Impacts of sonication power, sucrose solution concentration, and treatment time on the total color difference (ΔE) of apple slices during osmotic dehydration.

3.2. Surface area

The impacts of sonication power, sucrose solution concentration, and sonication time on the surface area of ultrasound-assisted osmotically dehydrated apple slices are demonstrated in Figure 4. As understood from this figure, the average surface area values were decreased with increasing sonication power levels from 0 to 150 W and osmotic solution concentrations from 30 to 50 °Brix. The average surface area of fresh apple slices, dehydrated samples, hot-air dried samples, and rehydrated samples was 10.00 cm^2, 8.62 cm^2, 5.61 cm^2, and 6.99 cm^2, respectively. The average surface area of apple slices decreased from 9.01 cm^2 to 8.22 cm^2 with increasing sonication power levels from 0 to 150 W. As well, with increasing treatment time, the surface area of dehydrated apple slices decreased. The results confirmed that the samples submitted to OD treatment (with or without ultrasound) for 10 and 60 min have maximum and minimum surface area, respectively. The average surface area of apple slices decreased from 8.69 cm^2 to 8.50 cm^2 with increasing osmotic solution concentration from 30% to 50%.





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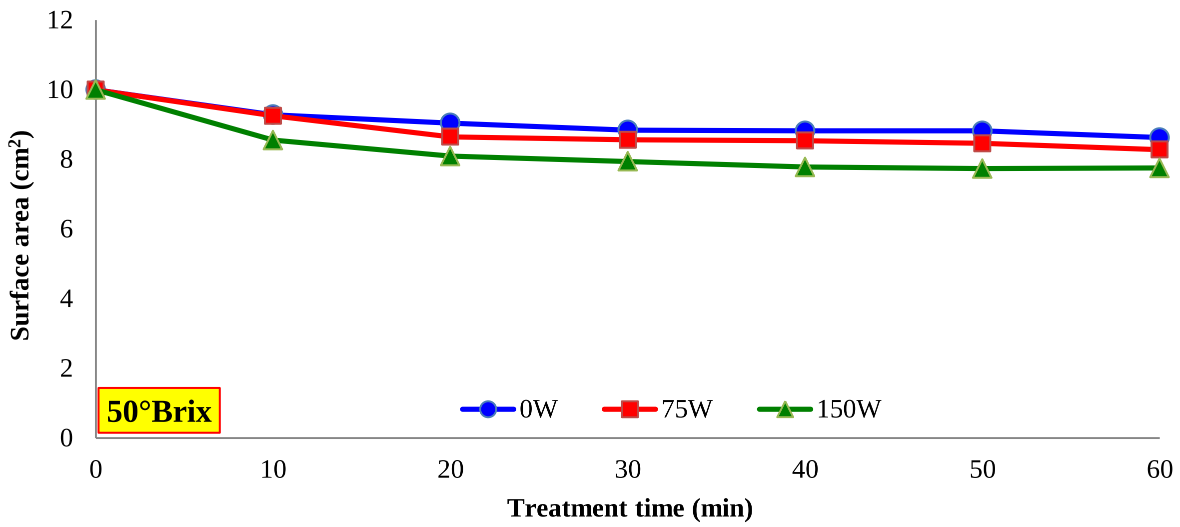

Figure 4. Impacts of sonication power, sucrose solution concentration, and treatment time on the surface area (cm^2) of apple slices during osmotic dehydration.

The rehydration procedure is mainly carried out before utilizing dehydrated fruit and vegetable products. Rehydration is the procedure of regaining water to dehydrated products [20]. Based on water absorption during the rehydration procedure, the mass, volume, and surface area of the rehydrated pieces increases. In this study, the surface area of rehydrated apple slices increased from 5.61 cm^2 to 6.99 cm^2 ($p<0.05$).

3.3. Kinetic modeling

The kinetics model with the highest R^2 value and the lowest SSE and RMSE values were selected as an appropriate model for modeling the ΔE index changes of apple slices during OD. The equation that satisfied these features was the logistic model (equation 1):

$$\Delta E= a/(1+b\,exp\,(-cx)) \qquad (1)$$

Where the ΔE is the total color difference index and the *a*, *b*, and *c* are the constants of the logistic model. The calculated coefficients (fitting data) of the logistic model, including equation constants, *a*, *b*, and *c*, are reported in Table 3 along with corresponding statistical data (R^2, SSE, and RMSE) for the experimental group. The R^2 values for all experiments were in the ranges of 0.936 to 0.999. Also, the values of SSE and RMSE for all conditions were in the ranges of 0.054 to 3.876 and 0.135 to 1.137, respectively. Figure 5 demonstrates the evaluation of fitted ΔE index data by the logistic model with empirical data (osmotic solution concentration=50°Brix). These results indicate that the logistic equation is suitable model for describing the ΔE index of dehydrated apple slices under the various sonication power levels and osmotic solution concentrations.

Table 3- The logistic model constants for total color difference index of apple slices during osmotic dehydration.

Solution concentration	Ultrasound treatment	a*	b	c	R^2	SSE**	RMSE***
30°Brix	Untreated (0W)	48.34	8.382	0.017	0.942	1.748	0.763
	Treated (75W)	20.48	3.37	0.055	0.999	0.054	0.135
	Treated (150W)	20.65	2.402	0.086	0.989	0.793	0.514
40°Brix	Untreated (0W)	17.18	1.354	0.026	0.936	1.253	0.646
	Treated (75W)	105.2	7.821	0.008	0.963	0.714	0.488
	Treated (150W)	24.16	1.533	0.058	0.994	0.399	0.365
50°Brix	Untreated (0W)	18.98	4.621	0.064	0.996	0.392	0.361
	Treated (75W)	20.92	4.876	0.095	0.989	1.464	0.698

Treated (150W)	22.91	5.384	0.123	0.975	3.876	1.137

* The *a*, *b*, and *c* are the constants of the logistic model.
** The sum of squares due to error (SSE)
*** Root mean squared error (RMSE)

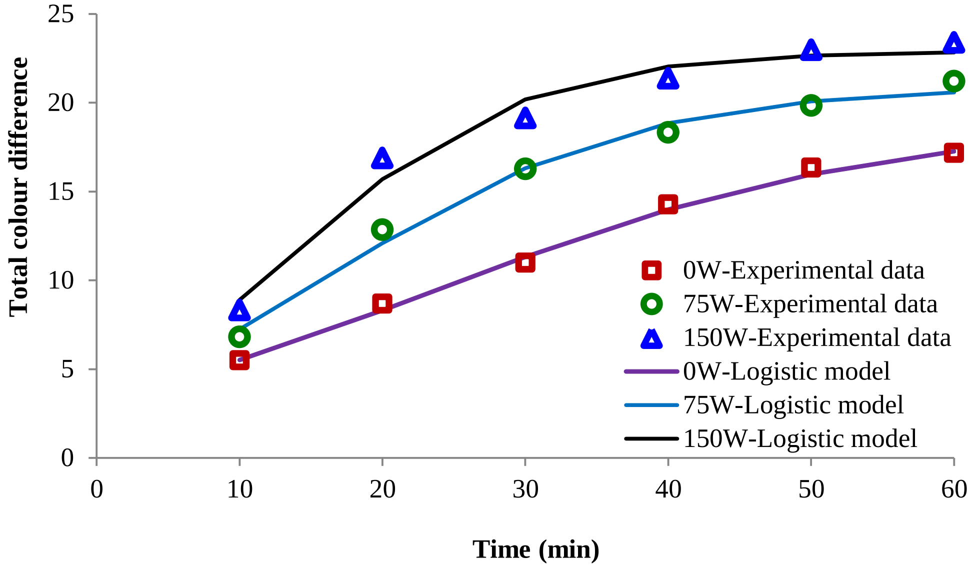

Figure 5. The fitting ability of logistic equation to empirical data of total color difference parameter of apple slices during osmotic dehydration (50°Brix).

4. Conclusion

Ultrasound treatment can be used directly for dehydration or pretreatment before OD procedure of fruit or vegetable particles. In this study, we examined the impacts of the OD procedure with or without ultrasound on the color parameters and surface area changes of apple slices. The lightness of dehydrated apple slices was decreased after OD process, but, the redness and yellowness indexes of samples were increased. The average surface area of fresh apple slices, dehydrated samples, hot-air drying samples, and rehydrated samples was 10.00 cm^2, 8.62 cm^2, 5.61 cm^2, and 6.99 cm^2, respectively, and the average surface area values were decreased with increasing sonication power levels from 0 to 150 W and osmotic solution concentrations from 30 to 50 °Brix. In addition, the Δ*E* index changes of apple slices during OD were modeled according to power, quadratic, and sigmoidal (gompertz, logistic, richards, morgan-mercer-flodin (MMF), and weibull) equations. The Δ*E* index changes were acceptably modeled by the logistic equation with the highest R^2 values (higher than 0.94) and the lowest SSE values (lower than 3.88) and RMSE values (lower than 1.14).

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اثرات تیمار فراصوت بر ویژگی‌های ظاهری برش‌های سیب در طول آبگیری اسمزی

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چکیده

آبگیری اسمزی روشی آسان برای حذف آب از قطعات میوه و سبزی‌ها است. در این مطالعه، برش‌های سیب به‌صورت اسمزی در محلول‌های هایپرتونیک مختلف از ساکارز با یا بدون کمک فراصوت آب‌گیری شدند. غلظت ساکارز، توان فراصوت و زمان تیماردهی فاکتورهای بودند که اثر آنها بر پارامترهای رنگی و تغییرات سطح برش‌های سیب در طول آبگیری اسمزی، مورد بررسی قرار گرفت. با افزایش توان فراصوت از ۰ وات به ۱۵۰ وات، مقادیر شاخص روشنایی (L^*) برش‌های سیب از ۸۰/۰۱ به ۷۴/۳۳ کاهش یافت. همچنین با افزایش غلظت محلول ساکارز از ۳۰ درجه بریکس به ۵۰ درجه بریکس، مقادیر شاخص روشنایی برش‌های سیب از ۷۹/۲۳ به ۷۵/۶۵ کاهش یافت. نتایج نشان داد که میانگین شاخص‌های a^* و b^* برش‌های سیب آبگیری شده در طول دوره آبگیری اسمزی افزایش یافته است. بیشترین مقادیر شاخص تغییرات رنگ کل (ΔE) (۲۳/۴) و کمترین مساحت سطح (۷/۹۸ سانتی‌متر مربع) برای برش‌های سیب تیمار شده با بیشترین توان فراصوت (۱۵۰ وات، ۴۰ کیلوهرتز) و غلیظ‌ترین محلول ساکارز (۵۰ درجه بریکس) بود. متوسط مساحت سطح برش‌های سیب تازه، نمونه‌های آب‌گیری شده، نمونه‌های خشک‌کننده با هوای گرم و نمونه‌های آبگیری مجدد شده به ترتیب ۱۰/۰۰ سانتی‌متر مربع، ۸/۶۲ سانتی‌متر مربع، ۵/۶۱ سانتی‌متر مربع و ۶/۹۹ سانتی‌متر مربع بود. نتایج نشان داد که معادله لجستیک بهترین معادله برای توصیف تغییرات شاخص ΔE برش‌های سیب تیمار نشده و تیمار شده در طول آبگیری اسمزی است.